

Infrared Microscopy with a ZnSe Solid Immersion Lens

NIST researchers applied solid immersion lens imaging to Infrared (IR) spectral microscopy to extend the spatial resolution of this technique and its utility in the analysis of advanced materials. IR microscopy is a technique that exploits the chemical specificity of infrared absorbance spectroscopy to allow the spatial mapping of chemical constituents of heterogeneous materials. The attainable spatial resolution in conventional IR microscopes is limited to values in the 20-30 micrometer range.

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Nondestructive analysis of the chemical composition of materials on microscopic length scales requires a spectroscopic technique with high spatial resolution, sensitivity sufficient to analyze small amounts of material, and chemical specificity. Infrared (IR) spectral microscopy is such a technique, exploiting the chemical specificity of infrared absorbance spectroscopy to allow the spatial mapping of chemical constituents of heterogeneous materials. This technique finds application in a wide variety of industry sectors, including chemicals, pharmaceuticals, forensics, and microelectronics. The rapid pace of device miniaturization in these and other sectors drives the need for chemical imaging techniques with spatial resolution relevant to the critical dimensions of the device or material. The attainable spatial resolution in conventional IR microscopes is limited to values in the 20-30 micrometer range. Although this resolution is suitable for a broad class of analytical problems, it is nearly two orders of magnitude worse than that of the best visible light microscopy. Improvements in the spatial resolution of this technique would extend its considerable power to a significant set of advanced materials analysis challenges for which the current resolution is insufficient.

Solid immersion lens (SIL) imaging involves the use of a lens (usually hemispherical) made from a material with a high index of refraction, n . Converging light impinging on the curved surface of the hemisphere forms an aberration free focus at the center of the bottom surface of the lens, yielding an increase in resolution by a factor of n . This improvement can be quite significant, particularly in the IR, where commonly used materials (*e.g.*, ZnSe, Ge) have indices in the range 2 to 4. This technique has been widely explored in the visible spectral region for optical data storage but little effort has been directed toward its use for chemical imaging with IR light. Application of SILs to IR microscopy offers the possibility of extending the spatial resolution of this technique and its utility in the analysis of advanced materials.

Development and validation of next-generation measurement techniques, such as high spatial resolution IR SIL microscopy, is of benefit to industrial and government customers.

A reflection mode, imaging IR microscope incorporating a ZnSe hemispherical SIL has been constructed and its imaging performance validated. Key components of the microscope include a broadband ($\sim 200\text{ cm}^{-1}$) IR laser source, an Indium Antimonide (InSb) focal plane array detector and a 0.65 numerical aperture, reflective Schwarzschild objective. The performance of the microscope was characterized by imaging $2.5\text{ }\mu\text{m}$ diameter polystyrene (PS) beads dispersed on both a gold film (no SIL), and the bottom surface of the SIL.

Figure 1. (a) $(95\pm 1) \times (95\pm 1)\text{ }\mu\text{m}$ reflection image of $2.5\text{ }\mu\text{m}$ PS spheres deposited onto a gold coated microscope slide acquired at $\lambda = 3.4\text{ }\mu\text{m}$. (b) $(36\pm 1) \times (36\pm 1)\text{ }\mu\text{m}$ SIL image of $2.5\text{ }\mu\text{m}$ PS spheres deposited onto the flat surface of the 2 mm diameter ZnSe hemispherical SIL, acquired at $\lambda = 3.4\text{ }\mu\text{m}$.

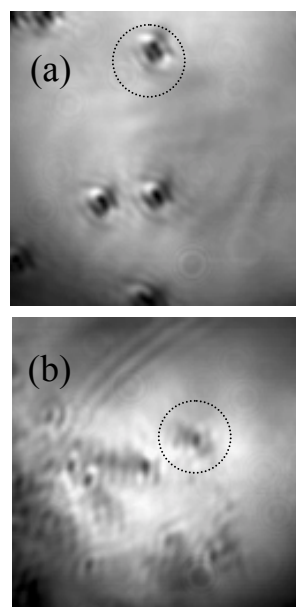


Figure 1(a) is a $(95\pm 1) \times (95\pm 1)\text{ }\mu\text{m}$ reflection image of the PS beads on gold imaged without the SIL at a wavelength $\lambda = 3.4\text{ }\mu\text{m}$. The PS spheres scatter light out of the collection cone of the objective and thus appear dark compared to the reflective gold. Figure 1(b) is a $(36\pm 1) \times (36\pm 1)\text{ }\mu\text{m}$ reflection image of the PS beads deposited on the bottom surface of the ZnSe SIL, also at a wavelength $\lambda = 3.4\text{ }\mu\text{m}$. Variation in the degree of total internal reflection (TIR) is the dominant contrast mechanism in this image. Most of the light in the angular range collected by the objective undergoes TIR at the ZnSe/air interface while propagating at the ZnSe/PS interface. Thus the PS spheres appear dark as the propagating light does not reach the reflection path detector.

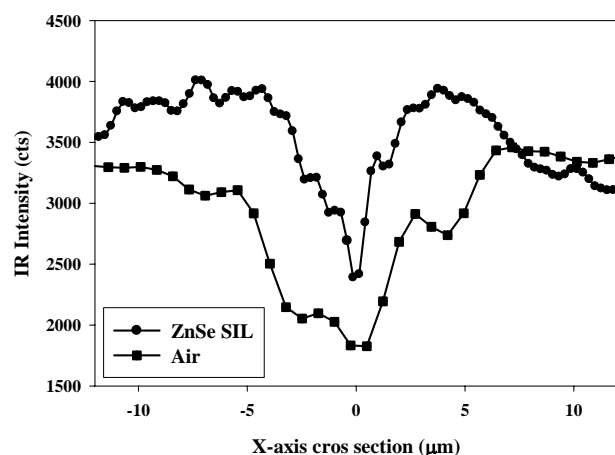


Figure 2. X-axis cross sections through PS spheres circled in air image (Fig. 1(a), squares) and ZnSe SIL image (Fig. 1(b), circles).

Future Plans: Acquisition of spectral images that contain the desired chemical contrast is a critical milestone for this project. A method for incorporating wavelength dispersion (e.g., FT interferometer) is currently being implemented to address this issue. Additionally, the construction of a transmission path microscope is underway. This version will incorporate a bimorph actuator for fine control over the sample/lens distance.

Figure 2 shows x-axis cross sections through the PS spheres circled in Figure 1, allowing a comparison of the apparent sphere sizes. The FWHM of the sphere feature in the air image (1(a)) is approximately 5.3 μm , reflecting some convolution of the microscope point spread function (PSF) with the actual PS sphere size. The FWHM of the sphere in the SIL image (1(b)) is approximately 3.2 μm , demonstrating the increased resolving power of the SIL microscope. Using a simple model of the PSF, the resolution with the SIL can be shown to increase by a factor of 2.3 over the value in air, in good agreement with the expected value of 2.43 (n_{ZnSe}). This comparison of air and SIL images demonstrates that IR imaging with off-the-shelf ZnSe hemispheres as immersion lenses is a straightforward approach to increasing the attainable spatial resolution in IR microscopy.

Publication in Preparation: A manuscript describing this work has been completed and will be submitted to Applied Physics Letters. This work has also been presented in invited talks at the Eastern Analytical Symposium, Dow Chemical and the Federation of Analytical Chemistry and Spectroscopy Societies (FACSS) national meeting.